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A Model of Large Quintessence Isocurvature Fluctuations and Low CMB Quadrupole

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Based on quintessence models with anti-correlation between the quintessence fluctuations and adiabatic perturbations in the other matter components, we show that if the quintessence potential is sufficiently steep at the end of inflation, the quintessence fluctuations can be large enough to sufficiently suppress the CMB power spectrum at low multipoles without excess gravitational waves. The leaping kinetic term quintessence and the crossover quintessence models, can realize such steep potential at the end of inflation, and therefore can give rise to a low CMB quadrupole as required by observations.

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The power spectrum of CMB temperature fluctuations, measured by COBE [1] and WMAP [2], has a smaller amplitude than expected theoretically on large angular scales. A small amplitude of the CMB fluctuations on large scales may be a consequence of the data analyses and limits of observation [3]. However, this may also be due to new physics for suppressing the CMB power spectrum at low multipoles. Many models of suppressing the CMB power spectrum at low multipoles have been proposed [4]. One possible model is based on the modification of the integrated Sachs-Wolfe (ISW) effect by dark energy perturbations [5, 6]. Dark energy perturbations can suppress the CMB power spectrum at low multipoles if their amplitude is large enough to modify the evolution of metric perturbations during dark energy domination. Moreover, they must have anti-correlation with the curvature perturbations, otherwise they enhance the low multipoles of the CMB spectrum [7].

The form of dark energy may be an evolving scalar field, known as quintessence [8]-[10]. Since the quintessence fluctuations are damped inside the horizon, we concentrate on the large scales fluctuations. On large scales, the transfer functions of the CMB temperature fluctuations can be written in conformal Newtonian gauge as [6, 20]

$$\begin{aligned} T_\ell(k,\eta_0) &= \frac{\sqrt{2\ell(\ell+1)}}{\zeta_i}\Big[(\Theta_* + \Phi_*)j_\ell(kD_*) \\ &\quad + \int_{\eta_*}^{\eta_0} d\eta(\Phi' - \Psi')j_\ell(kD)\Big], \\ &\approx -\frac{\sqrt{2\ell(\ell+1)}}{\zeta_i}\Big[\frac{1}{3}\Psi_* j_\ell(kD_*) \\ &\quad +2\int_{\eta_*}^{\eta_0} d\eta\,\Psi'\, j_\ell(kD)\Big], \end{aligned} \tag{1}$$

where a prime denotes a derivative with respect to the conformal time η, Θ is the temperature monopole, Φ is the gravitational potential, Ψ is the curvature fluctuation, j_ℓ is the spherical Bessel function, ζ_i is the initial value of the curvature perturbation on comoving hypersurfaces, $D = \eta_0 - \eta$ and the subscripts $*$ and 0 denote evaluation at recombination and present respectively. The angular power spectrum of the CMB can be expressed in terms of the transfer function as

$$\frac{\ell(\ell+1)C_\ell}{2\pi} = \int \frac{dk}{k} T_\ell^2(k,\eta_0)\mathcal{P}_{\zeta_i}(k), \tag{2}$$

here $\mathcal{P}_{\zeta_i}(k)$ is the power spectrum of ζ_i, defined as

$$\langle\zeta_i(\mathbf{k})\zeta_i(\mathbf{k}')\rangle = (2\pi)^3\delta(\mathbf{k}-\mathbf{k}')\frac{2\pi^2}{k^3}\mathcal{P}_{\zeta_i}(k). \tag{3}$$

The first term on the right hand side of eq. (1) corresponds to the gravitational redshift effects due to the photon's climb out of the potential well at last scattering. This is the ordinary Sachs Wolfe (SW) effect. The second term describes the fluctuations induced by the passage of CMB photons through the time evolving gravitational potential. This is the Integrated Sachs Wolfe (ISW) effect. To obtain the second line, we assume that the density fluctuations are adiabatic before quintessence domination, and that $\Phi = -\Psi$, i.e. anisotropic stress is negligible.

We suppose that the curvature perturbation Ψ is positive in the early epoch. The expansion of the universe makes Ψ decreases with time. Hence, it follows from eq. (1) that the ISW effect partially cancels the ordinary Sachs Wolfe effect. The contributions from the density perturbations can change the decay rate of Ψ, i.e. the ISW contribution. For quintessence, the quintessence fluctuations can increase the decay rate of Ψ, leading to a small amplitude of Θ_ℓ and also c_ℓ at low multipoles. The quintessence fluctuations can influence the evolution of Ψ when quintessence contributes a significant fraction of the total energy density. We assume that about the end of matter domination radiation can be neglected, so that the perturbed Einstein equation can be written as [21]

$$\Psi' + \mathcal{H}\Psi + \frac{k^2}{3\mathcal{H}}\Psi = \frac{1}{2}\mathcal{H}\left(\Omega_m\delta_m + \Omega_Q\delta_Q\right), \tag{4}$$

where the subscripts m and Q denote matter and quintessence, Ω is the density parameter, δ is the density contrast, $\mathcal{H} = a'/a$, and a is the scale factor. The above equation shows that the quintessence fluctuations can affect the evolution of Ψ if $|\delta_Q|$ is large enough. The decay rate of Ψ increases when δ_Q and Ψ have opposite sign, and decreases when δ_Q and Ψ have the same sign. Hence, the quintessence fluctuations can lead to the suppression of the CMB power spectrum at low multipoles if δ_Q is negative and $|\delta_Q|$ is large enough to enhance the ISW contribution.

If the quintessence field Q is light during inflation, it is nearly frozen and acquires quantum fluctuations [11]

$$\delta Q(k)_{\rm inf} = \frac{H_e}{\sqrt{2k^3}}, \tag{5}$$

where H_e is the Hubble parameter evaluated at the time of horizon exit, the quintessence field fluctuations δQ is in the conformal Newtonian gauge and k denotes the wavenumber of the perturbation mode. When the quintessence field is nearly frozen, its density contrast δ_Q in conformal Newtonian gauge is given by

$$\delta_Q = \frac{\delta\rho_Q}{\rho_Q} \simeq \frac{1}{V(Q)}\frac{dV(Q)}{dQ}\delta Q, \tag{6}$$

where ρ_Q is the energy density of quintessence and $V(Q)$ is the potential of the quintessence field. As long as the quintessence field is nearly frozen, its fluctuation δQ is approximately constant. Thus if the quintessence field is nearly frozen until the beginning of the radiation dominated epoch, the initial value of δ_Q in the radiation dominated era is given by

$$\delta_{Qi} \approx \frac{1}{V}\frac{dV}{dQ}\delta Q_{\rm inf}. \tag{7}$$

The evolution of δ_Q during the radiation and matter domination depends on the evolution of the quintessence field. Here, we consider the evolution of δ_Q only on superhorizon scales because $|\delta_Q|$ rapidly decreases with time on subhorizon scales. The evolution of the quintessence field is characterized by the equation of state parameter w_Q which is the ratio of the the pressure to the energy density. The quintessence fluctuations can be classified into adiabatic and isocurvature modes, according to the initial conditions. The adiabatic mode is the mode for which the entropy perturbations vanish, while the isocurvature modes correspond to the modes for which the curvature perturbations vanish or approximately vanish [12]. On large scales, the adiabatic mode is constant [13, 14] if w_Q is nearly constant. Nevertheless, its amplitude is limited by the adiabatic conditions, so that $|\delta_Q|$ cannot be adjusted to suppress the CMB power spectrum at low multipoles. For the isocurvature modes, their evolution depend on the value of w_Q. These perturbations modes decrease rapidly on large scales when $|w_Q|$ is approximately constant and significantly smaller than 1. In the context of tracking quintessence, this corresponds to the case when the quintessence field is in the tracking regime [15, 16]. Before the quintessence field starts the tracking regime, it is nearly frozen because w_Q is close to -1. Since $w_Q \approx -1$ when the potential energy of quintessence dominates the kinetic energy, the regime in which the quintessence field is frozen is called the potential regime. During this regime, the isocurvature modes are approximately constant [6, 13]. In general, the quintessence field can be frozen if the Hubble drag term $3H\dot{Q}$ in its evolution equation dominates the potential term dV/dQ. Here, a dot denotes the time derivative and H is the Hubble parameter. In the case of tracking quintessence, there may exist a short period of kinetic regime between inflation and potential regime. The isocurvature modes increase during this regime. Since the kinetic regime is short and $|\delta_Q|$ decreases during the transition from the kinetic regime to the potential regime [13, 16], the total growth of $|\delta_Q|$ is small.

We are interested in the suppression of CMB spectrum at low multipoles via the quintessence fluctuations, which can occur when $|\delta_Q|$ is large enough during quintessence domination. From the above summary, we see that the magnitude of δ_Q can be large during quintessence domination if its initial value is large and the quintessence field is nearly frozen initially and always frozen until quintessence domination. If the quintessence field is nearly frozen until quintessence domination, the amplitude of δ_Q during quintessence domination will be equal to $|\delta_{Qi}|$ approximately. Since the quintessence field is nearly frozen initially, the initial value of δ_Q is given by eq. (7). Thus, the amplitude of δ_Q during quintessence domination can be large if the amplitude of $\delta Q_{\rm inf}$ or the initial value of $\left|\frac{1}{V}\frac{dV}{dQ}\right|$ at the end of inflation is large. The amplitude of $\delta Q_{\rm inf}$ usually depends on H_e, while the initial value of $\left|\frac{1}{V}\frac{dV}{dQ}\right|$ depends on the quintessence model. For simple quintessence models, whose potential slope does not change much during quintessence evolution, the ratio $\left|\frac{1}{V}\frac{dV}{dQ}\right|$ cannot be large at the end of inflation, because the quintessence potential must be flat enough at present to drive an accelerated expansion of the universe today. Hence, the CMB spectrum at low multipoles can be suppressed sufficiently if $\delta Q_{\rm inf}$ is large enough. In the simplest case, this requires H_e to be larger than the observational bound [6], i.e. there are excess gravitational waves. This excess gravitational waves problem can be solved if the field fluctuation δQ is amplified between the inflationary and present epoch. This amplification can occur if the kinetic coefficient of the quintessence field varies in time [17].

Alternatively, the problem of excess gravitational waves can be avoided if the quintessence potential is steep enough at the end of inflation. This is because the steep potential can lead to a large $|\delta_{Qi}|$ although the amplitude of $\delta Q_{\rm inf}$ is small. However, the quintessence potential must be flat enough at present to drive an accelerated expansion of the universe. We now consider whether the quintessence potential can be sufficiently steep at the end of inflation and flat enough to drive an accelerated expansion of the universe today. Let us consider the simple exponential quintessence model, whose potential can be written as $V(Q) = \bar{m}_p^4 \exp(-\lambda Q/\bar{m}_p)$, where $\bar{m}_p = (8\pi G)^{-1/2}$ is the reduced Planck mass. Thus, $\frac{1}{V}\frac{dV}{dQ} = -\frac{\lambda}{\bar{m}_p}$, and therefore the magnitude of δ_{Qi} can be large if λ is large. In the early epoch, the quintessence field can be frozen although its potential is steep, because quintessence is not a dominant component. Using the evolution equation for the quintessence field, one can show that [15]

$$\left|\frac{1}{V}\frac{dV}{dQ}\right| = \frac{\lambda}{\bar{m}_p} = \frac{\sqrt{3}}{\bar{m}_p\sqrt{\Omega_Q}}\sqrt{1+w_Q}\left|1+\frac{1}{6}\frac{d\ln x}{d\ln a}\right|, \quad (8)$$

where $x = (1+w_Q)/(1-w_Q)$. The above equation shows that, although λ is large, the quintessence field can be frozen, i.e., $w_Q \approx -1$, if Ω_Q is sufficiently small. In order to drive an accelerated expansion of the universe, the quintessence field has to be slowly rolling at the present epoch. When the quintessence field is slowly rolling, its evolution equation yields $\frac{1}{3H^2}\frac{d^2V}{dQ^2} \simeq -\frac{\dot{H}}{H^2}$. This is a slow-roll condition for the quintessence field. During the present epoch, quintessence is the dominant component, so that $\dot{H} = -\dot{Q}^2/(2\bar{m}_p^2)$. Since $V > \dot{Q}^2/2$and $H^2 \simeq V/(3\bar{m}_p^2)$ when the quintessence field is slowly rolling, the slow-roll condition requires $\lambda^2 < 1.5$, i.e. the quintessence potential should not be too steep. Unfortunately, the amplitude of CMB quadrupole will be in agreement with the observation if $\lambda \gg 1$. However, if λ is a time-dependent parameter, the quintessence potential might be able to be sufficiently steep at the end of inflation and flat enough at present. An exponential quintessence model with time dependent λ is conveniently described by a leaping kinetic term model [18]. The Lagrangian of this quintessence is

$$\mathcal{L}(\chi) = \frac{1}{2}(\partial\chi)^2\kappa^2(\chi) - \bar{m}_p^4\exp[-\chi/\bar{m}_p]\,. \quad (9)$$

Using the field variable $Q = K(\chi)$, where $\kappa(\chi) = \partial Q/\partial\chi$, the above Lagrangian becomes

$$\mathcal{L}(Q) = \frac{1}{2}(\partial Q)^2 - \bar{m}_p^4\exp[-K^{-1}(Q)/\bar{m}_p]\,. \quad (10)$$

It is convenient to use the field Q to study the evolution of quintessence because its kinetic term has a canonical form. The evolution of this field depends on the form of $\kappa(\chi)$. We use

$$\kappa(\chi) = \kappa_{\min} + \tanh\left(\frac{\beta}{\bar{m}_p}[\chi-\chi_1]\right) + 1, \quad (11)$$

where $\kappa_{\min}$, χ_1 and β are constant. In the early epoch, $\chi \ll \chi_1$ so $\kappa \simeq \kappa_{\min}$. Therefore, we have $\frac{1}{V}\frac{dV}{dQ} \simeq -(\bar{m}_p\kappa_{\min})^{-1}$. In our consideration, the field χ and Q are nearly frozen during the initial stage. As the universe evolves, the Hubble drag term decreases due to decreasing Hubble parameter, while the potential term is approximately constant because Q and χ are nearly frozen. When the Hubble drag term is small enough, the fields Q and χ are able to roll down their potentials. Consequently, the field χ increases and becomes larger than χ_1 during matter domination. As a result, the kinetic coefficient κ increases and therefore w_Q decreases towards -1 again. The evolution of this quintessence field has a tracking behavior. The present value of w_Q depends on β, while the present value of Ω_Q depends on χ_1 if β is fixed. The evolution of w_Q is shown in figure 1.

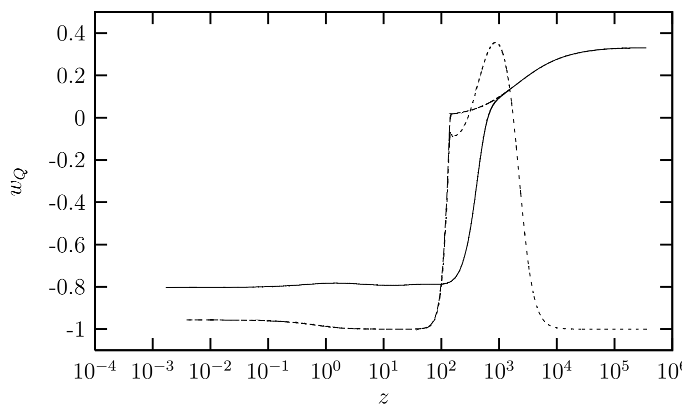

FIG. 1: Evolution of w_Q. The solid line and long dashed line show the tracking solutions, where $\beta = 1$ for the solid line and $\beta = 500$ for the long dashed line. The dashed line corresponds to the case when the quintessence field starts in the potential regime and $\beta = 500$. In this plot, we set $\kappa_{\min} = 8.7 \times 10^{-4}$ and $\Omega_Q = 0.7$ at the present epoch.

It is easy to see that $|\delta_{Qi}|$ is large when $\kappa_{\min}$ is small. At first sight, this looks similar to the existing literature because the magnitude of the quintessence fluctuations is enhanced by a kinetic coefficient [17]. Nevertheless, the physical motivation is different. In the literature, the quintessence field fluctuation is amplified between the inflationary and present epoch by a varying kinetic coefficient. In our analysis, the exponential quintessence can give rise to a large $|\delta_{Qi}|$ if λ is large. The varying kinetic coefficient is used to push w_Q towards -1 at the present epoch without amplifying the fluctuations in the quintessence field. The high energy physics model of this type of quintessence, called crossover quintessence, has been proposed by Wetterich [19]. Here, we are interested in the behavior of this quintessence model so we use the simple form of the kinetic coefficient in eq. (11).

Since we suppose that the quintessence field Q is frozen initially, it will be frozen until quintessence domination if its initial value Q_i is larger than the tracking solution value [15]. In our consideration, the value of Q_i is chosen such that w_Q evolves as shown in figure 2. It can be seen in this figure that the redshift z_c at which the quintessence field leaves the potential regime decreases if Q_i increases. The evolution of Ω_Q is approximately the same for all chosen Q_i so we do not plot it.

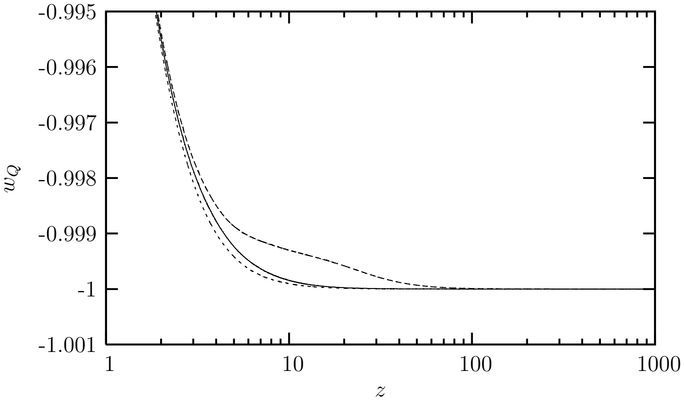

FIG. 2: Evolution of w_Q. The long dashed line represents the case where the quintessence fluctuations have no effect on the evolution of Ψ, the dashed line represents the case where the quintessence fluctuations lead to a large ISW contribution and the solid line represents the case where the CMB power spectrum at low multipoles is sufficiently suppressed by the quintessence fluctuations. For these line styles, we set $\kappa_{\min} = 8.7 \times 10^{-4}$ and $\beta = 500$. The value of Q_i for the long dashed lines is smallest, while the one for the dashed lines is largest. These representations of line styles will be used in all subsequent figures.

To compute the initial conditions for the quintessence fluctuations, we suppose that the isocurvature fluctuations in quintessence have (anti-) correlation with adiabatic fluctuations in the other matter, so that the initial conditions for quintessence fluctuations can be written as [6] $\delta_{Q\mathrm{int}} = \delta_{Q\mathrm{ad}} + \delta_{Q\mathrm{iso}}$ and $u_{Q\mathrm{int}} = u_{Q\mathrm{ad}} + u_{Q\mathrm{iso}}$. Here, the subscripts int, ad and iso denotes the mixed initial conditions, adiabatic initial conditions and isocurvature initial conditions respectively. The density contrast δ_Q and momentum density u_Q in these expressions are in conformal Newtonian gauge. When the quintessence field is nearly frozen, the density contrast δ_Q is roughly equivalent to the gauge invariant density contrast Δ_Q because $\Delta_Q = \delta_Q + 3(1 + w_Q)\Psi$. Moreover, the momentum density u_Q and the gauge invariant momentum density U_Q are the same. Thus, we can use the gauge invariant formulas in [21] to compute the adiabatic initial conditions for quintessence and the other species, e.g., photon, baryon, neutrino and CDM. These initial conditions are written in terms of ζ_i, where $\zeta_i = 1$. For isocurvature modes, the value of $\Delta_{Q\mathrm{iso}}$ is computed using eq. (7). The field fluctuation δQ_{inf} is written in terms of curvature perturbation as [11, 22] $\delta Q_{\mathrm{inf}} \simeq \sqrt{2\epsilon}\zeta_i \bar{m}_p \simeq \sqrt{0.125R}\zeta_i \bar{m}_p$, where ϵ is the slow roll parameter of inflaton and R is the relative amplitude of the tensor to scalar perturbations. If we hold R fixed, the value of $\Delta_{Q\mathrm{iso}}$ will depend only on $\kappa_{\min}$. Since the observational bound of R is $R < 0.28$ at the 95% confidence level [2], we set $R = 0.01$ in our calculation. The choice of R does not affect the results of the calculation because different choices of R can give the same results if the value of $\kappa_{\min}$ is adjusted. The value of $U_{Q\mathrm{iso}}$ can be computed using [6] $\Delta_{Q\mathrm{iso}} = U_{Q\mathrm{iso}}\left(s - 3w_Q + 3c_{aQ}^2 - 1\right)$, where $s = \frac{1}{2}\left[6w_Q - 3c_{aQ}^2 - 2 \pm \sqrt{9c_{aQ}^4 + 12c_{aQ}^2 - 20}\right]$ and c_{aQ}^2 is the adiabatic sound speed of quintessence. In our case, the quintessence field is frozen initially so $c_{aQ}^2 = -7/3$ [16] and therefore $U_{Q\mathrm{iso}} = -\Delta_{Q\mathrm{iso}}/5$.

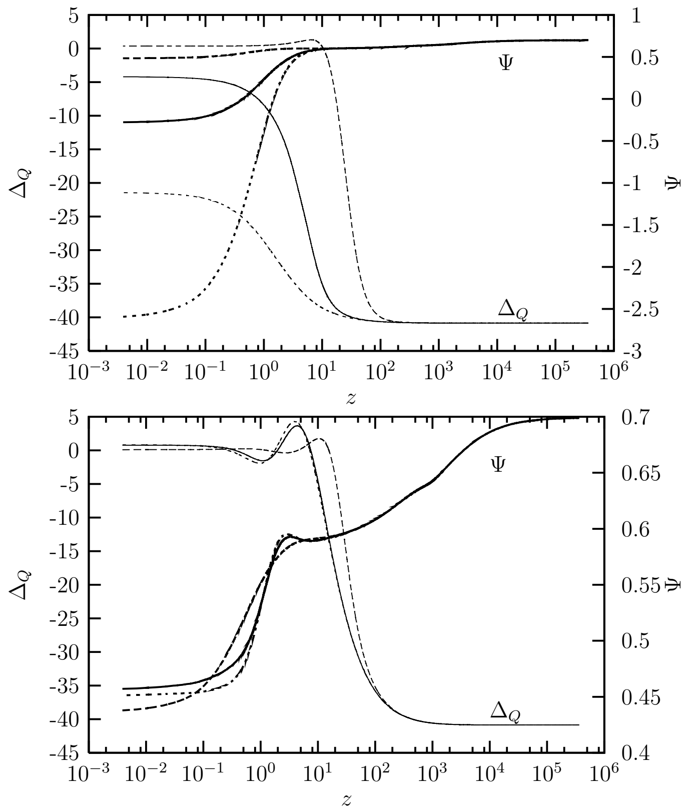

FIG. 3: Evolution of Δ_Q (thin lines) and Ψ (thick lines) for the models whose w_Q is plotted in figure 2. The top panel shows a mode whose wavelength is larger than the horizon today ($k = 2 \times 10^{-4}\mathrm{Mpc}^{-1}$), while the bottom panel shows a mode which enters the horizon about the end of matter domination ($k = 1 \times 10^{-3}\mathrm{Mpc}^{-1}$).

We use CMBEASY [23] to compute the evolutions of Δ_Q and Ψ and plot them in figure 3. From this figure, we see that the magnitude of Δ_Q decreases when w_Q increases from -1. For a given redshift, the decay rate of Ψ increases with increasing $|\Delta_Q|$. Thus, the ISW contribution increases with decreasing z_c (or equivalently with increasing Q_i). This is because $|\Delta_Q|$ will start to decrease at lower redshift if z_c decreases. On small scales, the quintessence fluctuations decrease after horizon crossing. Thus, the quintessence fluctuations lead to less modifications of Ψ' compared with the case of large scales. Because of the oscillation of the quintessence fluctuations, Ψ' oscillates after horizon crossing. Therefore, the amount of the ISW contribution does not increase with decreasing z_c.

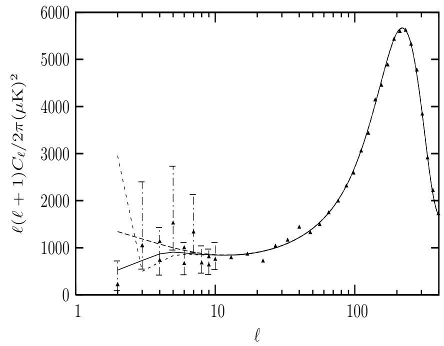

FIG. 4: The CMB power spectrum for different choices of Q_i. The data points from WMAP 3-year results are denoted by the solid triangles. The error bars show the 68% confidence level.

The CMB power spectrum is computed using CMBEASY and shown in figure 4. In this figure, we set $\Omega_b h^2 = 0.0223$, $\Omega_m h^2 = 0.127$, $\Omega_Q = 0.73$, $h = 0.73$, $\tau = 0.09$, $n_s = 0.95$ and $\beta = 500$.

From this figure, we see that the amplitude of the CMB power spectrum at low multipoles decreases with decreasing z_c for a suitable range of z_c. This is because the ISW contribution increases when z_c decreases. The value of z_c must be smaller than the redshift of matter-radiation equality, otherwise the amount of the quintessence fluctuation is not large enough to modify the ISW contribution. Nevertheless, if z_c is too small, the CMB quadrupole increases but a few higher multipoles decrease when z_c decreases

Since the ISW contribution depends on the amount of the quintessence fluctuations at low redshift, the amplitude of the CMB power spectrum at low multipoles also depends on $\kappa_{\rm min}$. For a fixed z_c, the amplitude of the CMB spectrum decreases with decreasing $\kappa_{\rm min}$ due to the increasing $|\Delta_{Qi}|$. The different values of $\kappa_{\rm min}$ can lead to the same amplitude of the CMB power spectrum if the value of z_c for the case of small $\kappa_{\rm min}$ is larger than the one for the case of large $\kappa_{\rm min}$. However, the value of $\kappa_{\rm min}$ must not be too large or too small compared with the value which is chosen here. If $\kappa_{\rm min}$ is too large, the quintessence fluctuation will have no effect on the CMB power spectrum because $|\Delta_{Qi}|$ is too small. If $\kappa_{\rm min}$is too small, the CMB power spectrum at low multipoles will be enhanced by the quintessence fluctuations due to the large ISW contribution.

The enhancement of the CMB quadrupole when z_c is too small can be understood by considering the CMB transfer function. we plot the CMB transfer functions in figure 5. This figure shows that the ISW contribution for $\ell = 2$ is much enhanced around its peak due to the quintessence fluctuations. If the amount of ISW contribution is too large, it leads to an enhancement of the CMB quadrupole. For $\ell = 4$, quintessence fluctuations lead to less ISW contribution because the ISW contribution peaks at a scale which is smaller than the horizon size today and the quintessence fluctuations decrease inside the horizon. Therefore, the CMB spectrum at $\ell = 4$ still decreases with decreasing z_c although the CMB quadrupole increases with decreasing z_c.

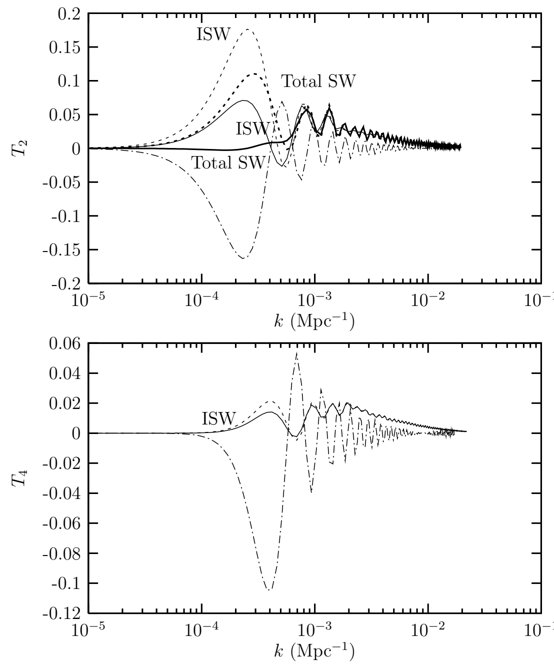

FIG. 5: Radiation transfer function of the CMB power spectrum in figure 4. The top panel corresponds to $\ell = 2$, while the bottom panel corresponds to $\ell = 4$. The ordinary SW effect is represented by the dash-dotted lines. The thin lines represent the ISW effect and the thick lines represent the total (ordinary + integrate) SW effect. The solid and dashed lines correspond to the different ISW contributions which lead to the CMB power spectra in figure 4.

The quintessence fluctuation can lead to the suppression of the CMB power spectrum at low multipoles if its amplitude are large enough during quintessence domination and it has an anticorrelation with the adiabatic perturbations in the other matter. Assuming that the quintessence fluctuation is generated during inflation, its amplitude can be large during quintessence domination if the amplitude of its initial value $\Delta_{Qi} \simeq \frac{1}{V}\frac{dV}{dQ}\delta Q_{\rm inf}$ is large and the quintessence field is nearly frozen until quintessence domination. It has been shown that the quintessence field may leave the potential regime at low redshift because its coarse-grained part is driven towards a large value by its quantum fluctuations [24]. Thus, if the initial amplitude of the quintessence fluctuation is large, the amplitude of quintessence fluctuations can be large enough to enhance the ISW contribution, and therefore suppress the CMB power spectrum at low multipoles. For simple quintessence models, $|\Delta_{Qi}|$ can be large if $\delta Q_{\rm inf}$ is large, leading to excess gravitational waves. In this work, we avoid the excess gravitational waves by keeping $\delta Q_{\rm inf}$ below observational bound. The large $|\Delta_{Qi}|$ can be obtained by enhancing the initial value of $\left|\frac{1}{V}\frac{dV}{dQ}\right|$. However, To drive an accelerated expansion of the Universe, the quintessence potential must be flat today. Hence, the quintessence field usually has small $\left|\frac{1}{V}\frac{dV}{dQ}\right|$ in the early epoch. We found that the potential of leaping kinetic term quintessence can be sufficiently steep initially and be nearly flat today. Thus, this quintessence model can produce large fluctuations to explain the observed low CMB quadrupole if the value of $\kappa_{\rm min}$ is chosen appropriately. This quintessence model has a tracking behaviour but the amplitude of the CMB power spectrum at low multipoles depends on z_c, or equivalently the initial value of the quintessence field.

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